OHIO ACADEMY OF SCIENCE
GEOLOGY FIELD TRIP
23 April 1978

The explanation of the Field Trip is copied from *The Ohio Journal of Science*, v.78, no.A (April Program and Abstracts Supplement), p. 4.

As an experimental departure from the traditional automobile tour from site to site, the Geology Department is planning a field geophysical exercise and demonstration. Departmental seismic equipment will be used to detect a buried pre-glacial valley as may be done during a search for new supplies of ground water.

Members of the Geology Department will give a brief explanation of the project and of the principles of seismic exploration, after which the party will be bussed to a field site. Here they will witness a truck-mounted rig drill a shot hole, the geophones laid out, and the shot hole loaded and shot. The data from the shot will be displayed, and copies of the data obtained from an earlier shot on the same site will be distributed. After a break for lunch, the party will divide into smaller groups and members of the Geology Department will demonstrate to each group how to interpret the data to determine if a buried valley is present.

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The Seismic Refraction Method
Applied to the Study of Buried Valleys

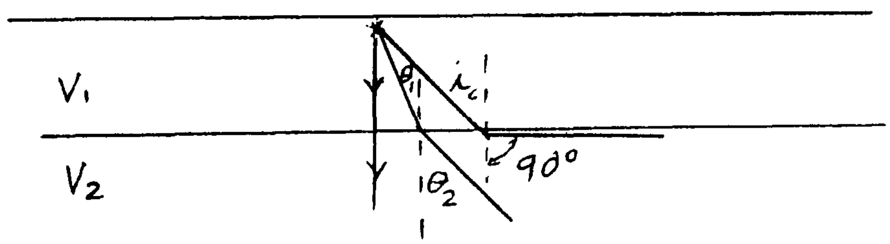
In the seismic refraction method compressional waves are commonly injected into the earth by a dynamite explosion. The explosion is detonated in a drill hole to increase the efficiency for wave generation. The arrival of the waves at a point on the surface is sensed by a geophone or detector which generates an electrical signal that is connected to the recording unit. For refraction surveys the first arrival of the seismic wave energy at each geophone is the primary data.

The waves can reach the geophones by several paths. The shortest path distance is for waves to travel directly through the near surface material. If this material transmits the wave at velocity V_1, then the time of arrival at a geophone, that is a distance, X, from the source, is $t = x/v_1$.

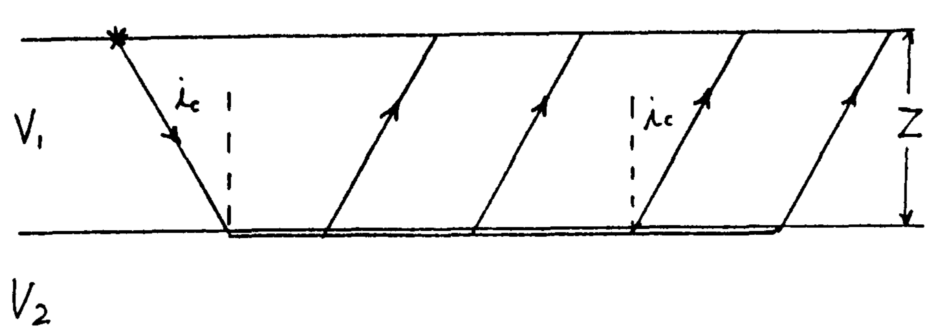
If there is a zone of material with a higher velocity, V_2, at depth Z, the waves will propagate downward and be refracted at the boundary between the two media. This refraction is controlled by Snell's Law.

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{V_1}{V_2}$$

In this equation θ_1 is the angle between the direction of propagation of the wave in medium 1 and the normal to the interface. θ_2 represents the corresponding angle in medium 2.



For $V_2 > V_1$ we have $\theta_2 > \theta_1$. The critical angle, $\theta_1 = i_c$, when $\theta_2 = 90°$, is the maximum angle at which refraction can occur. At this critical angle the wave which enters the lower medium propagates along the interface. This wave along the interface generates upward travelling waves which reenter medium 1 at the critical angle. These are called head waves.



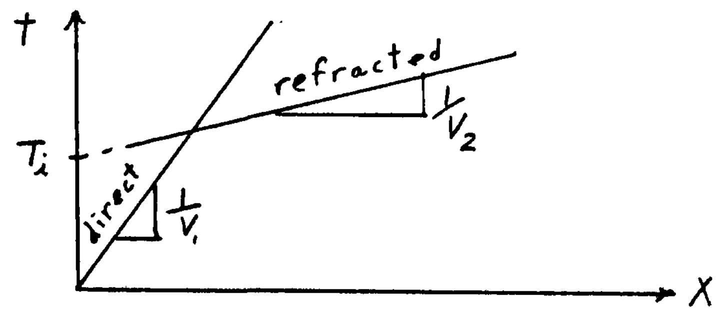
These waves travel a greater distance between source and geophone than the direct waves but along the lower part of their path they travel with the higher velocity. At large distances these head waves will arrive before the direct waves. The time at which they become the first arriving energy depends on the velocities and the depth.

The time of arrival of the waves at a geophone which is a distance X from the source is:

$$t = \frac{X}{V_2} + \frac{2z\sqrt{V_2^2 - V_1^2}}{V_1 V_2}$$

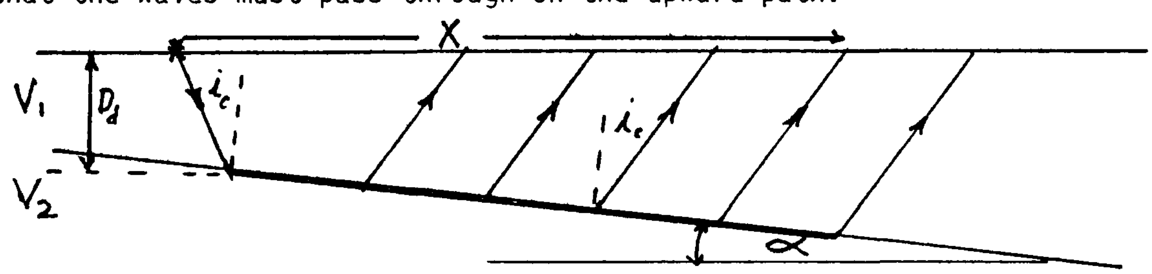
This shows that t is linearly related to X with slope $1/V_2$ and intercept $T_i = \frac{2Z\sqrt{V_2^2 - V_1^2}}{V_1 V_2}$

The graph below shows the arrival times for both direct and "refracted" waves.



Note that beyond the cross-over point the refracted waves arrive earlier than the direct waves. Since V_1 and V_2 can be found from the observed slopes, Z can be calculated from the intercept time.

When looking for buried valleys the interface of interest is between the bedrock and the glacial material that has filled the bedrock valleys. In this case the interface is not horizontal but is sloping. For a sloping interface with the seismic waves propagating in the down dip direction, the arrival times are progressively delayed. This is due to the increasing thickness of material that the waves must pass through on the upward path.



The arrival time is still proportional to X but the slope is now increased corresponding to a decreased down dip apparent velocity, V_d. Since neither the dip, α, nor the velocity V_2 are known, the depth cannot be found.

If a reverse shot is fired at the right of the figure so that the waves travel up-dip, the slope of t vs. X will be lower. This corresponds to an increased up-dip apparent velocity, V_u.

Solving the equations involved in the direct and refracted waves resulting from the forward and reverse shots allows the parameters of interest to be determined. The resulting relationships are:

$$i_c = \frac{1}{2}\left[\sin^{-1}\left(\frac{V_1}{V_d}\right) + \sin^{-1}\left(\frac{V_1}{V_u}\right)\right]$$

$$\alpha = \frac{1}{2}\left[\sin^{-1}\left(\frac{V_1}{V_d}\right) - \sin^{-1}\left(\frac{V_1}{V_u}\right)\right]$$

$$V_2 = V_1 / \sin i_c$$

$$D_d = \frac{V_1 T_{id}}{2 \cos i_c \cos\alpha} \quad \text{or} \quad D_u = \frac{V_1 T_{iu}}{2 \cos i_c \cos\alpha}$$

where T_{id} and T_{iu} are the intercepts of the down-dip and up-dip refracted wave lines on the t vs. X graph. D_d and D_u are the depths to bedrock below the down-dip and up-dip shots.

The bedrock surface is not a smooth dipping surface but, if it is moderately flat, the above analysis can be applied with reasonable success and small deviations can be identified and interpreted with respect to the overall structure.

Since the surface of the ground is uneven we do not have the simple situation pictured in the last figure. In addition, the material at the surface is unsaturated and frequently it is poorly consolidated. This produces a material with low seismic wave velocity and irregular thickness. To partially remove this problem it is usual to choose a datum plane below this layer and to correct the times to correspond to the times that could occur if the shot and geophones were located on the datum plane. To do this we must subtract the time for the waves to travel from the shot to the datum plan (called shot correction) and the time for the waves to travel up from the datum plane to the surface (called detector correction). The equation is the same for both corrections.

$$\text{Correction time} = \frac{\sqrt{V_1^2 - V_0^2}}{V_1 V_0} \cdot h$$

where V_0 is the velocity in the unsaturated material and h is the distance between the shot and datum surface (including shot hole depth) or the distance between the geophone and the datum surface.

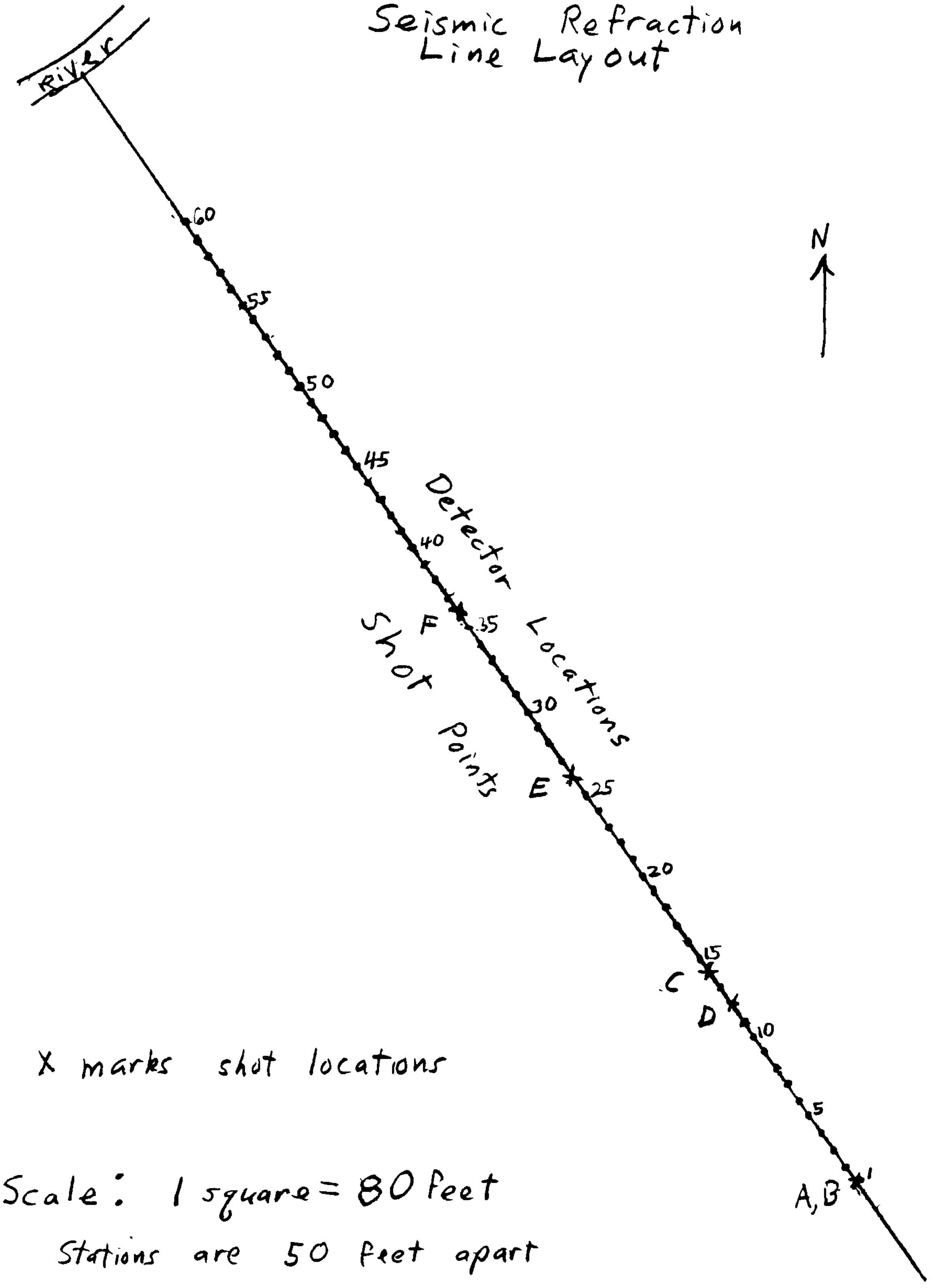
References

D.H. Griffiths and R.F. King, Applied Geophysics for Engineers and Geologists, Pergamon Press, Oxford (1965).

W.M. Telford, L.P. Geldart, R.E. Sheriff, and D.A. Keys, Applied Geophysics. Cambridge University Press, Cambridge (1976).

Milton B. Dobrin, Introduction to Geophysical Prospecting, McGraw-Hill, New York (1976), Third Edition.

Fairgrounds Road
Greene County
Seismic Refraction Line Layout



X marks shot locations

Scale: 1 square = 80 feet

Stations are 50 feet apart

Fairgrounds Road, Greene County
Seismic Refraction Survey Elevations

Station Number	Elevation (Feet)	Height above datum	Detector time corr.	Station Number	Elevation (Feet)	Height above datum	Detector time correct.
1	829	27	20 ms	31			ms
2	830	28	20	32			
3	831	29	21	33			
4	830	28	20	34			
5	831	29	21	35			
6	830	28	20	36	815	13	10
7	830	28	20	37			
8	829	27	20	38			
9	829	27	20	39			
10	829	27	20	40			
11	829	27	20	41			
12	828	26	19	42			
13	828	26	19	43			
14	828	26	19	44			
15	828	26	19	45			
16	828	26	19	46			
17	829	27	20	47			
18	828	26	19	48			
19	830	28	20	49			
20	830	28	20	50			
21	830	28	20	51			
22	830	28	20	52			
23	830	28	20	53			
24	830	28	20	54			
25	829	27	20	55			
26	829	27	20	56			
27				57			
28				58			
29				59			
30				60			

Shot Time Correction

Shot	Elevation	Depth of Shot	Height of shot above datum	Time correct
A	829 ft	13 ft	14 ft	10 ms
B	829 ft	13 ft	14 ft	10 ms
C	828 ft	13 ft	13 ft	10 ms
D	829 ft	8 ft	19 ft	14 ms
E	829 ft	13 ft	14 ft	10 ms
F	815 ft	13 ft	0 ft	0
G				
H				

Fairgrounds Road, Greene County
Seismic Refraction First Arrival Data

Geophone Station	Distance from shot	Time – Uncorrected	Time Correction	Corrected Time	Quality Code
	Shot A – Forward				
2	50 ft	38 ms	30 ms	8 ms	Good
3	100	51	31	20	G
4	150	55	30	25	Poor
5	200	65	31	34	G
6	250	68	30	38	P
7	300	82	30	52	G
8	350	85	30	55	P
9	400	90	30	60	Fair
10	450	100	30	70	P
11	500	106	30	76	G
12	550	—	29	—	No Good
13	600	131	29	102	G
	Shot B – Forward				
13	590 ft	—			NG
14	640	131 ms	29 ms	102 ms	F
15	690	134	29	105	G
16	740	137	29	108	G
17	790	139	30	109	G
18	840	144	29	115	G
19	890	149	30	119	G
20	940	149	30	119	G
21	990	153	30	123	G
22	1040	156	30	126	G
23	1090	—	30	—	NG
24	1140	163	30	133	F
	Shot C – Reverse				
13	50 ft	—	29 ms	—	NG
12	100	42	29	13 ms	G
11	150	49	30	19	G
10	200	56	30	26	G
9	250	59	30	29	F
8	300	69	30	39	G
7	350	82	30	52	G
6	400	84	30	54	F
5	450	87	31	56	P
4	500	95	30	65	P
3	550	—	31	—	NG
2	600	108	30	78	P

Fairgrounds Road, Greene County
Seismic Refraction First Arrival Data

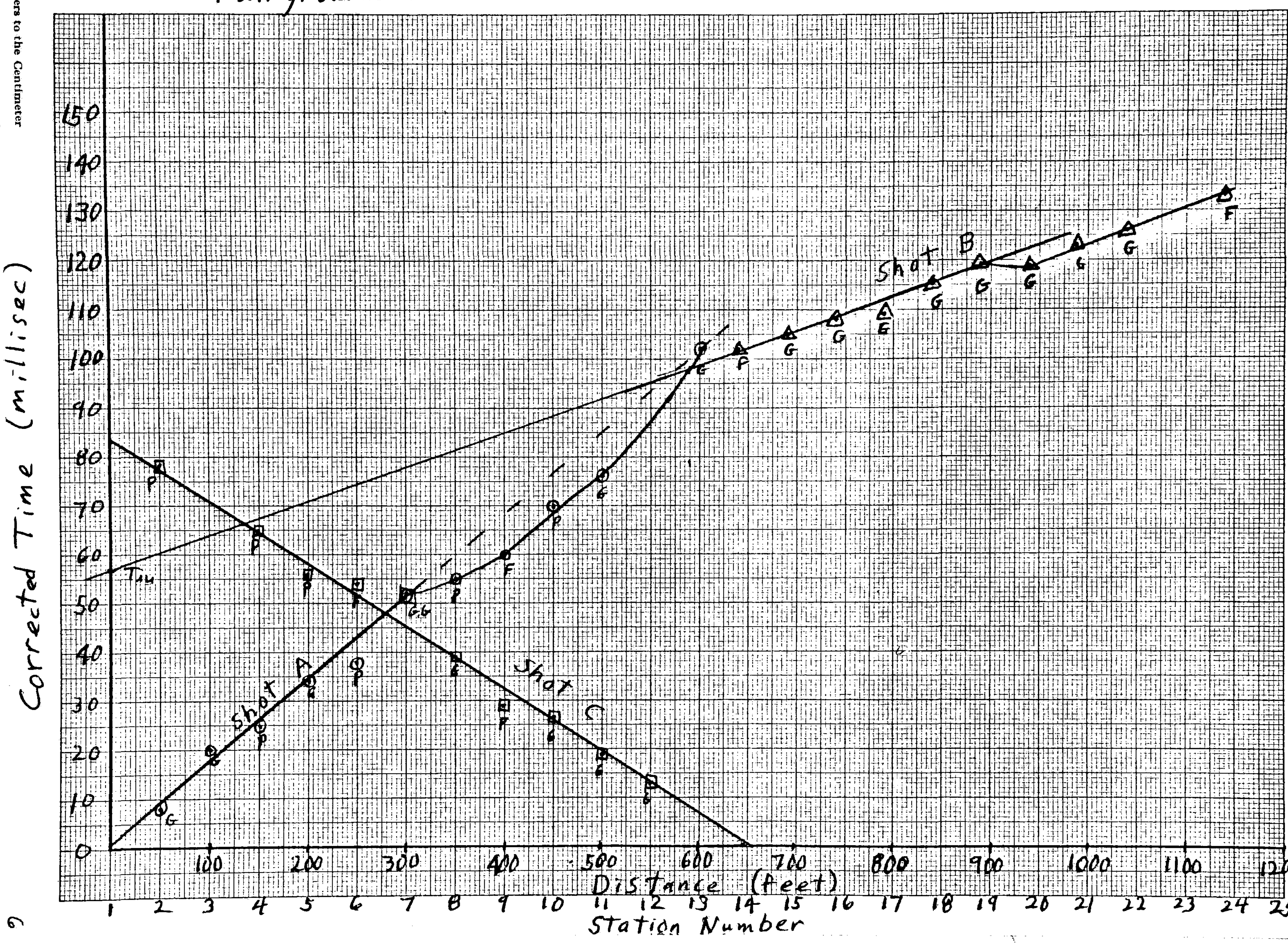
Geophone Station	Distance from shot	Time - uncorrected	Time Correction	Corrected Time	Quality Code
		Shot D - Forward			
13	50 ft	32 ms	33 ms	−1 ms	G
14	100	46	33	13	G
15	150	52	33	19	G
16	200	59	33	26	G
17	250	70	34	36	P
18	300	72	33	39	G
19	350	80	34	46	P
20	400	85	34	51	G
21	450	92	34	58	P
22	500	101	34	67	VP
23	550	—	34	—	NG
24	600	117	34	83	VP
		Shot E - Reverse			
25	50 ft	35 ms	30 ms	5 ms	G
24	100	44	30	14	G
23	150	51	30	21	G
22	200	57	30	27	G
21	250	63	30	33	P
20	300	68	30	38	P
19	350	—	30	—	NG
18	400	—	29	—	NG
17	450	95	30	65	F
16	500	104	29	75	F
15	550	113	29	84	P
14	600	121	29	92	F
		Shot F - Reverse			
25	650 ft	130 ms	20 ms	110 ms	P
24	700	134	20	114	G
23	750	139	20	119	F
22	800	143	20	123	G
21	850	149	20	129	VP
20	900	157	20	137	G
19	950	168	20	148	G
18	1000	170	19	151	G
17	1050	174	20	154	F
16	1100	179	19	160	G
15	1150	184	19	165	P
14	1200	189	19	170	G

The film tore on Shot F and the time break was lost. Time zero was estimated. The absolute times are not reliable. The detector to detector differences should not be altered.

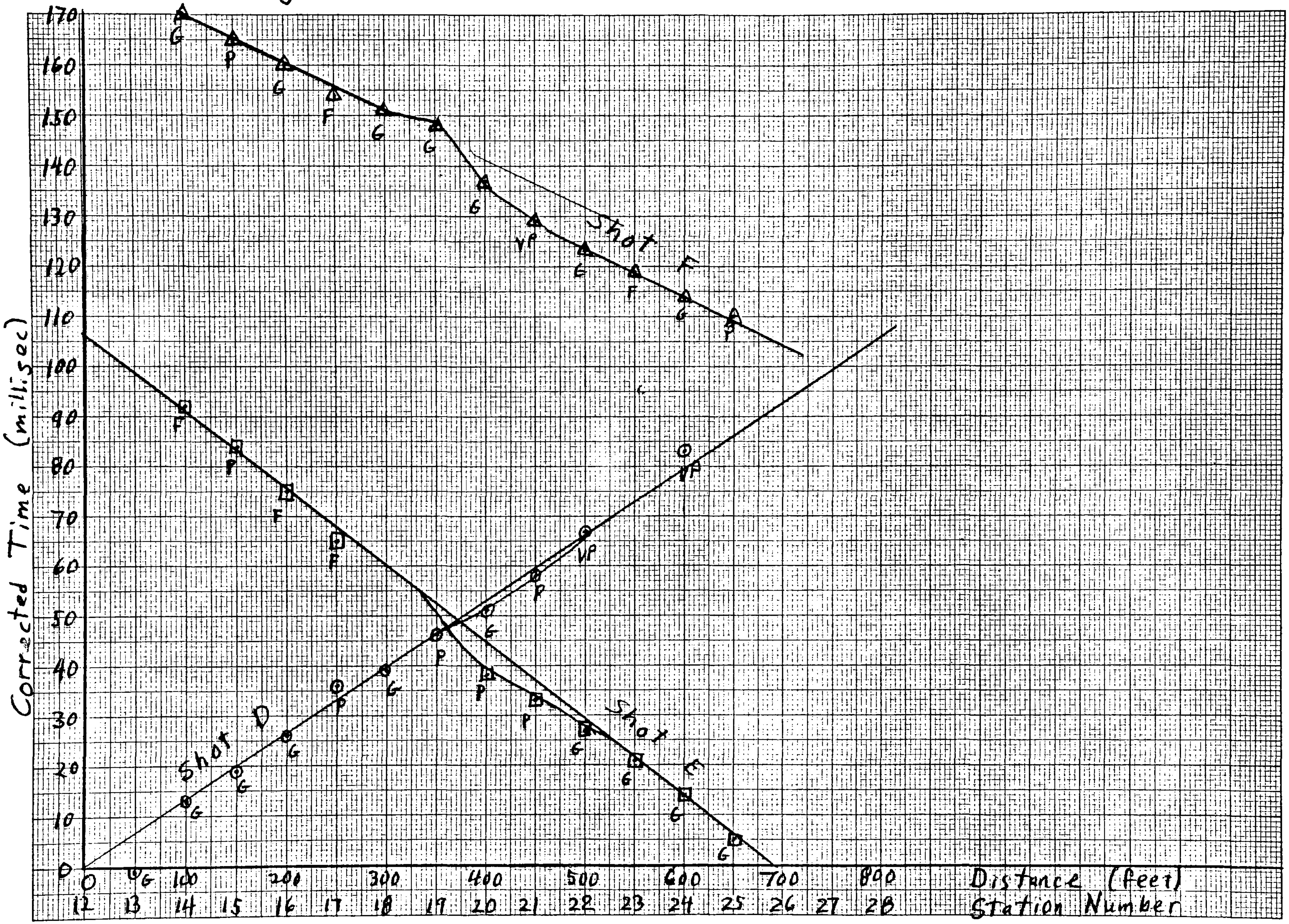
Fairgrounds Road, Greene County
Seismic Refraction First Arrival Data

Geophone Station	Distance from Shot	Time-uncorrected	Time Correction	Corrected Time	Quality Code		

Fairgrounds Road Seismic Refraction Shots A, B, and C



Fairgrounds Road Seismic Refraction Shots D, E, and F



Fairgrounds Road
Seismic Refraction Analysis

The velocity of seismic waves in the unsaturated zone is approximately 1400 feet/sec.

The elevation of the water table was assumed to be constant at 802 feet due to evidence from shot hole drilling and the first points on the refraction records. The datum plane to which all times were corrected was chosen to be the water table.

If the shot was fired at the datum plane, the arrival would have been sooner. The corresponding correction time is:

$$\frac{\sqrt{V_1^2 - V_0^2}}{V_0 V_1} \cdot \text{(height above datum)}$$

where V_0 is the velocity in the unsaturated material and V_1 is the velocity in the saturated material.

V_0 = 1400 ft./sec ; V_1 = 6950 ft./sec approximately

Sample calculation for shot A

Height above datum = surface elevation - shot hole depth - datum elevation

= 829 - 13 - 802 = 14 feet

Shot correction $= \frac{\sqrt{(6950)^2 - (1400)^2}}{1400 \cdot 6950} \frac{\text{sec}}{\text{ft}} \cdot 14 \text{ ft}$

$= .0098 \text{ sec} \approx 10 \text{ millisec}$

For the detector the same equation must be applied.

Sample calculation for station 4

Dectector correction $= \frac{\sqrt{(6950)^2 - (1400)^2}}{1400 \cdot 6950} \frac{\text{sec}}{\text{ft}} \cdot 28 \text{ ft}$

$= 20 \text{ millisec}$

Velocity Determinations

Shot A slope:

$$V_A = \frac{300\text{ ft} - 0\text{ ft}}{52\text{ms} - 1\text{ms}} = \frac{300\text{ ft}}{51 \times 10^{-3}\text{ sec}} = 5900\text{ ft/sec}$$

Shot B slope:

$$V_B = \frac{900' - 550'}{119.5\text{ms} - 95\text{ms}} = 14{,}300\text{ ft/sec}$$

Shot C slope (magnitude):

$$V_C = \frac{650' - 0'}{83\text{ms} - 0} = 7800\text{ ft/sec}$$

Shot D slope:

$$V_D = \frac{600'}{79\text{ms}} = 7600\text{ ft/sec}$$

Shot E slope (magnitude):

$$V_E = \frac{690\text{ ft}}{106\text{ ms}} = 6500\text{ ft/sec}$$

Shot F slope (magnitude):

$$V_F = \frac{700' - 500'}{123.5\text{ms} - 104\text{ms}} = 10{,}300\text{ ft/sec}$$

Slopes V_A, V_C, V_D, and V_E represent the saturated glacial fill. The average of these values is V_1 = 6950 ft/sec.

Slope V_B represents the apparent updip velocity of the bedrock surface.

Slope V_F represents the apparent downdip velocity of the bedrock surface.

The critical angle is:

$$i_c = \frac{1}{2}\left[\sin^{-1}\left(\frac{V_1}{V_F}\right) + \sin^{-1}\left(\frac{V_1}{V_B}\right)\right] = \frac{1}{2}\left[\sin^{-1}\left(\frac{6950}{10300}\right) + \sin^{-1}\left(\frac{6950}{14300}\right)\right]$$

$$= \frac{1}{2}\left(42.5^\circ + 29.1^\circ\right) = 35.8^\circ$$

The bedrock dip is:

$$\alpha = \frac{1}{2}\left[\sin^{-1}\left(\frac{V_1}{V_F}\right) - \sin^{-1}\left(\frac{V_1}{V_B}\right)\right] = \frac{1}{2}\left(42.5^\circ - 29.1^\circ\right)$$

$$= 6.7^\circ$$

It is dipping toward the south east if the seismic line is perpendicular to the strike.

The bedrock velocity is:

$$V_2 = \frac{V_1}{\sin i_c} = \frac{6950\text{ ft/sec}}{\sin 35.8^\circ} = 11{,}900\text{ ft/sec}$$

The depth to the bedrock at Station 1 can be estimated using:

$$D_u = \frac{V_1 T_{iu}}{2 (\cos i_c)(\cos \alpha)}$$

where T_{iu} is the intercept of the line for the updip apparent velocity (shot B line in this case).

$$D_u = \frac{6950 \text{ ft/sec} \cdot 57 \times 10^{-3} \text{ sec}}{2(\cos 35.8^\circ)(\cos 6.7^\circ)} = 246 \text{ ft}$$

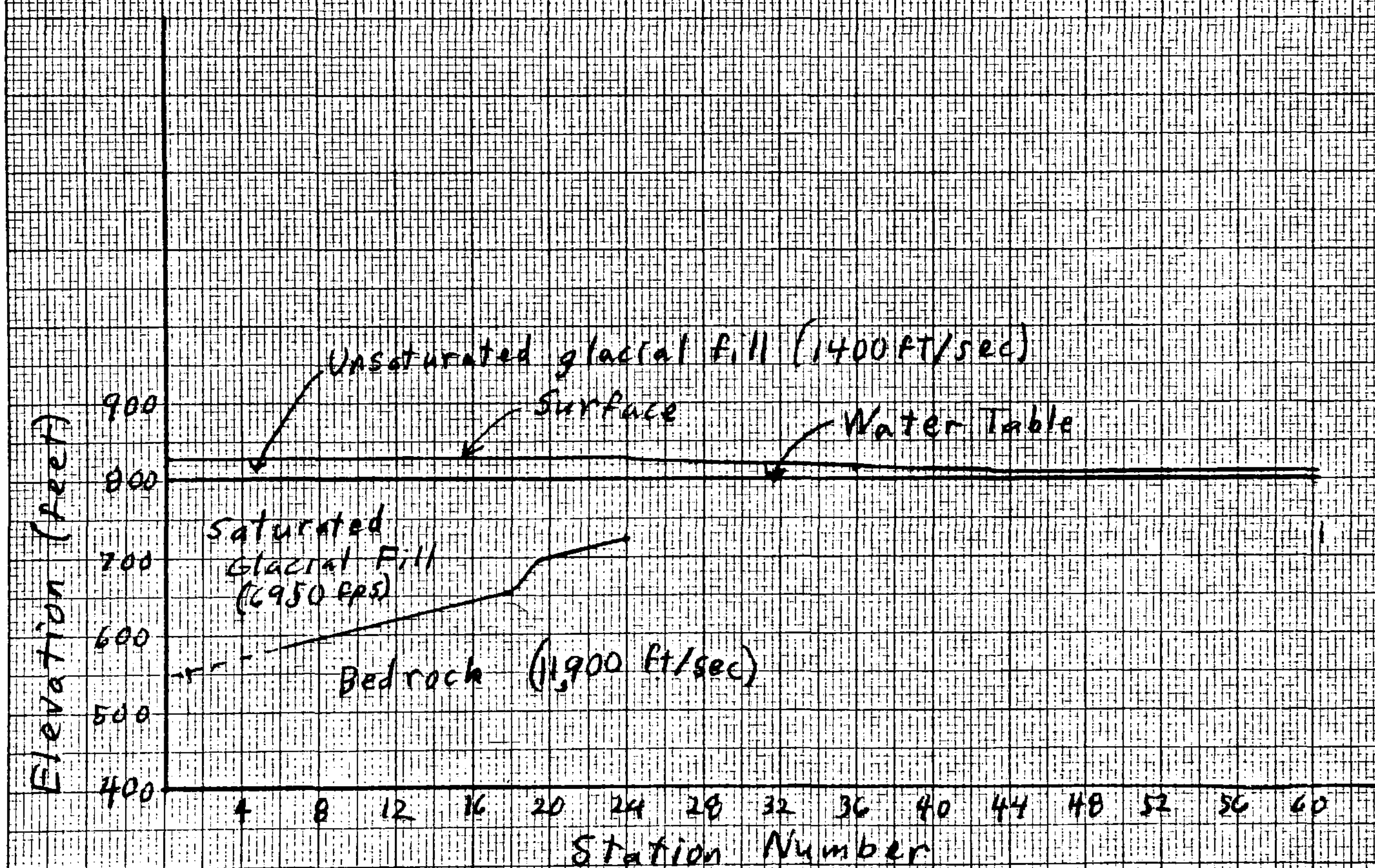
So the elevation of the bedrock surface at station 1 is (802-246) = 556 feet, if the bedrock is uniformly sloping. The graphs indicated a break in the surface observed at station 18. This break is an offset of 7 msec on Shot F and 4 msec on Shot B. Using the average of 5.5 msec and the velocity of 6950 ft/sec this indicates an offset of 38 feet on the sloping bedrock surface in the vicinity of station 19. The surface is shifted upward at stations larger than 19 relative to stations smaller than 19.

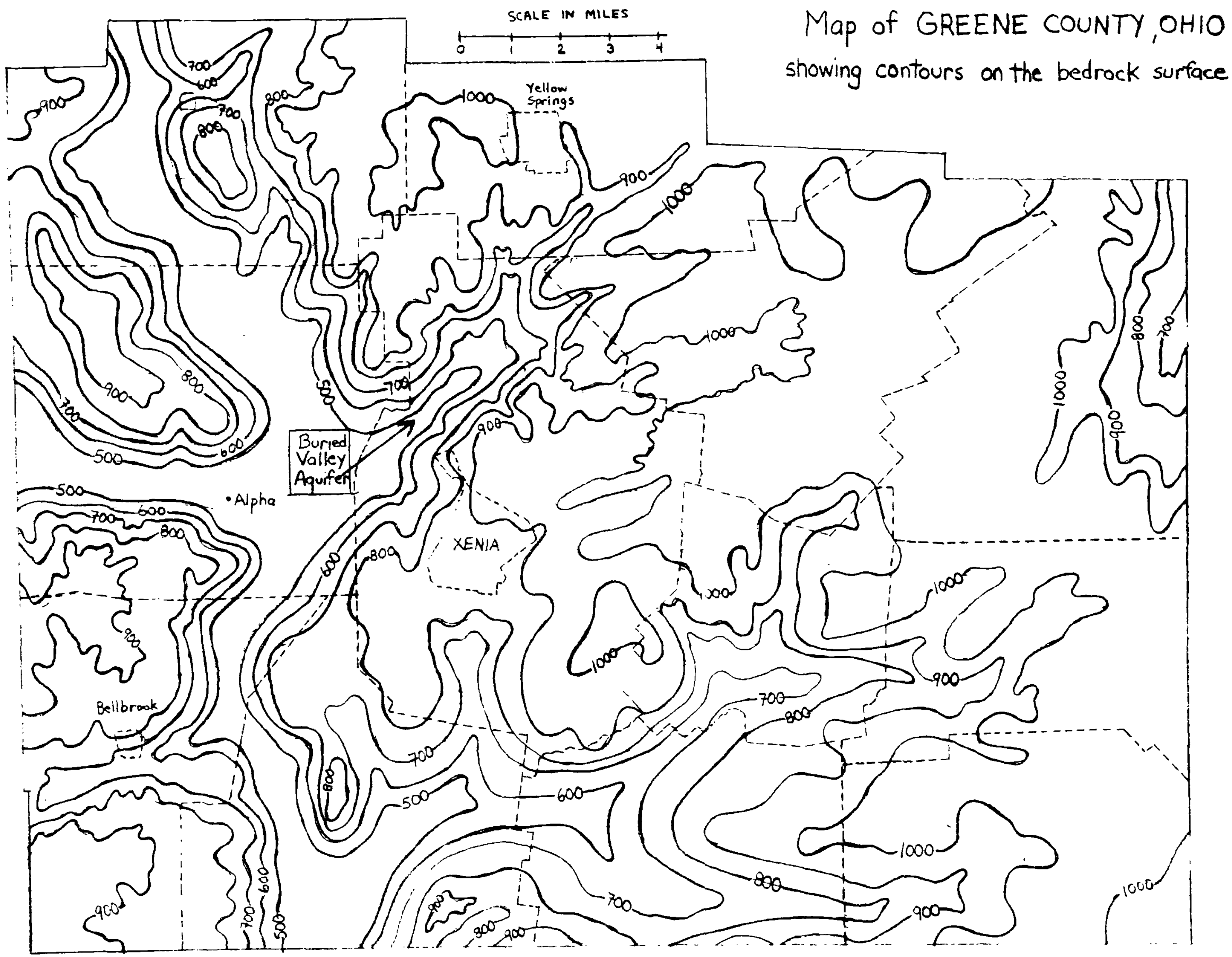
The bedrock elevation at station 18 is 556 feet + 850 tan 6.7° = 656 feet

The bedrock elevation at station 24 is 556 feet + 1150 tan 6.7° + 38 feet = 729 feet

Evidence from an earlier survey indicates that the bedrock is dipping to the northwest at the southeast end of the line. There may be a maximum depth near station 5.

Cross Section along
Fairgrounds Road
Determined by Seismic Refraction
(Vertical Exaggeration = 2)





from Plate 1, The Water Resources of Greene County by Stanley E. Norris, Ohio Department of Natural Resources, Division of Water, Bulletin 19, 1950.

WHAT'S IN A BURIED VALLEY?

There are some pretty useful things to be found within buried valleys in the Dayton area: economically valuable deposits of sand and gravel, extensive groundwater supplies, and helpful clues about the hydrology of Ohio in earlier eras. These are but a few of the reasons that the study of subsurface bedrock topography remains an important part of applied geology at Wright State. Much of the existing information about depth to bedrock in the Dayton area comes from well logs and other records obtained from shallow boreholes. This data is conspicuously lacking in the center of the deepest bedrock lows where bedrock topography probably varies rapidly, but where most water wells are completed without penetrating the full thickness of unconsoidated valley fill. In areas of deeply buried bedrock such surface techniques as seismic refraction have become a valuable tool in further exploring the details of buried valley depth and width, and slope of buried valley center line (talweg).

The general features of the bedrock surface in Greene County, Ohio are given in figure 1. This figure was drawn more than two decades ago on the basis of well logs, but remains generally accurate in all of the major features shown. The basic difficulty with this figure is the lack of detail concerning the exact extent and depth of buried valleys, such as the one crossed by Fairground Road in Western Greene County. It is now recognized that these buried valleys were originally carved in bedrock by a pre-glacial drainage network. They were further modified by drainage disruption during the onset of glaciation, and by various torrenti meltwater streams which were either superimposed by the structure of the melting ice sheets, or let down onto the bedrock through soft pro-glacial deposits. Climatologists and hydrologists are especially interested in conditions which prevailed directly in front of the advancing ice sheets during the early stages of glaciation. Such information is provided by the record of stream reversal when the advancing ice dammed the pre-galcial Teays River but most other information was destroyed by subsequent glacial erosion. For this reason it is important that we know something about the exact slope of buried valley floors, along with the identity of those bedrock channels which were carved in that dramatic episode of river disruption known as the "Deep Stage."

Even if one does not care about the glacial history of Ohio, there are important economic reasons for seeking buried valleys. As indicated in our discussion of buried valley formation, some valleys were formed by glacial meltwaters while others were pre-glacial river valleys which were simply filled with glacial drift during the ice advance. Bedrock channels which actually carried water from the ice sheet are likely to contain well-sorted fluvial deposits. Since some of the meltwater streams were rather large torrents, these fluvial gravels can be extremely coarse. The location of these gravels is an important discovery in an urban area where various construction projects require gravel but where most of the terrain is mantled with thick glacial tills with high clay and silt content.

One of the most important properties of buried valleys in the Dayton area, and especially of those valleys which contain glacio-fluvial deposits, is their ability to store groundwater in the poor spaces between particles. The ability of unconsoidated materials to store and transmit water is greatly improved if the material is well sorted (ie, consists of particles all of which are about the same size). In western Greene County many areas are underlain by Ordovidian shales, which are especially poor conductors of groundwater. Some of these areas are characterized by thick glacial till over shale, and therefore offer unusually poor groundwater resources. The location of buried valleys, along with a knowledge of the exact configuration of already known buried valleys, becomes crucial in the development of water supplies in these areas. When bedrock channels are located they can become the water supply for a surprisingly large number of homes. It is typical for twelve inch wells in the area of Beaver Creek to produce as much as 500 gallons per minute from thirty feet of screened gravel formation within bedrock lows. Gravel packed municipal wells in gravels near the Mad River in extreme western Montgomery County have exhibited specific capacities of up to three thousand gallons per minute per foot of drawdown. That's quite some groundwater resource!

GEOLOGICAL SURVEY